United States Coast Guard

Office of Engineering

FIELD TESTING AND DEVELOPMENT CENTER

REPORT NO. 449

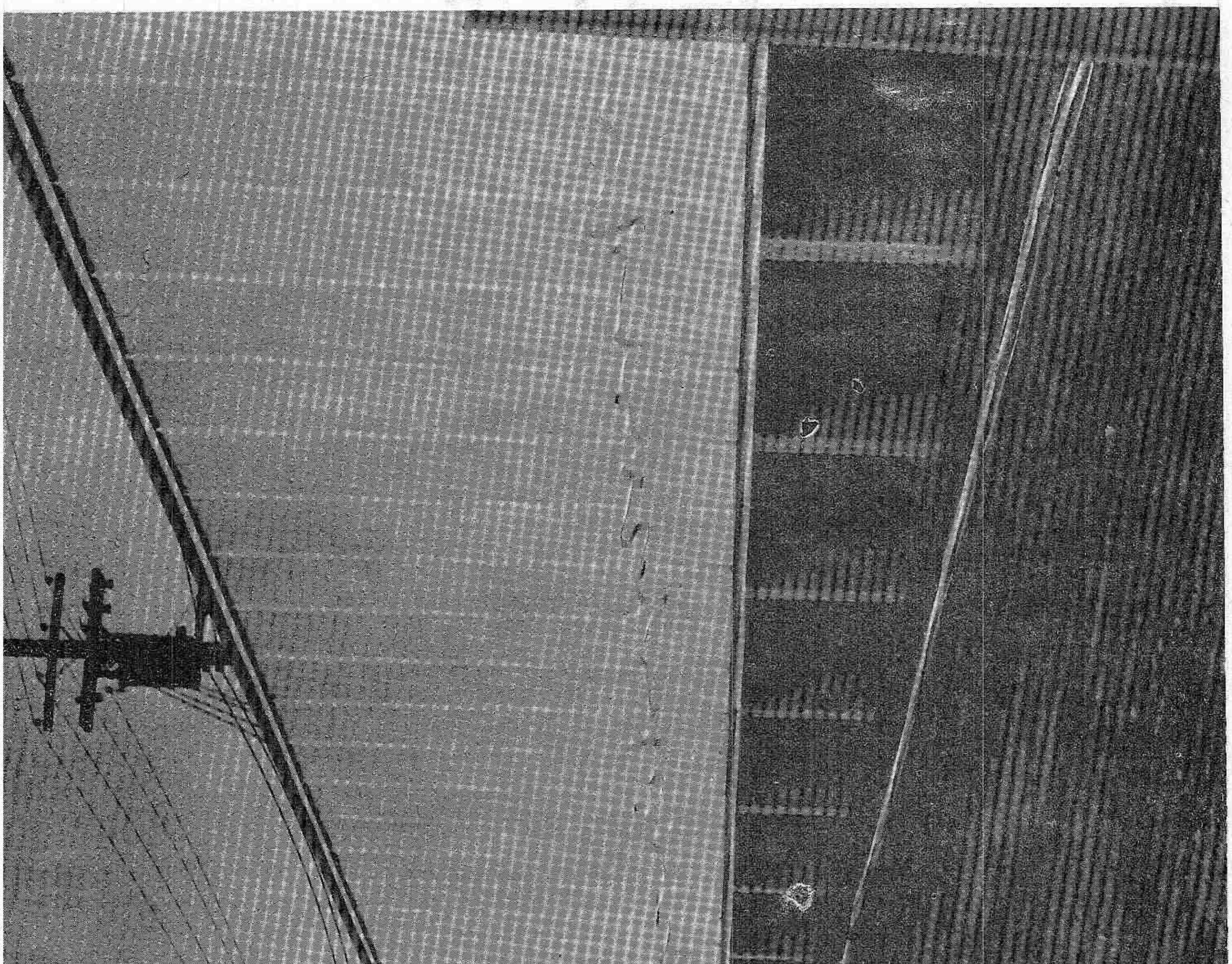
PROJECT 3973/01/01

RECOIL PROPERTIES OF ROPE

7 NOVEMBER 1966

Washington, D.C.

20226



UNITED STATES COAST GUARD

FIELD TESTING AND DEVELOPMENT CENTER

TEST REPORT

~~PROJECT~~ USCG 3973/01/01

6 RECOIL PROPERTIES OF ROPE

By

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14 p. 12

Date: 7 NOVEMBER 1966

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Authority: Comdt(ETD) ltr 3973/01/01 ser 640 of 19 February 1964, w/encl.

ABSTRACT

This report covers the test program to determine the recoil properties of synthetic rope. It describes the test facility developed to test the recoil properties and the procedure used in testing. The results of the test are presented in graphical form showing the relative kinetic energy available upon release for the various lines tested.

The conclusion drawn from the test program is that, while synthetics have levels of recoil energies, the disadvantage can be overcome by careful sizing of the line for a given application.

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1.0 INTRODUCTION:

Over the years, synthetic materials have largely replaced the traditional natural fibers in the manufacture of ropes for marine use. The synthetic materials, such as nylon, polyester, polyethylene, and polypropylene offer many distinct advantages in comparison with natural fibers. The synthetics are highly resistant to deterioration from rotting and mildew; are lighter in weight and smaller in size for comparable strength; have better wear resistance; and in most cases, have superior energy absorbing capability under shock load. The last advantage can create a hazardous condition, if the stored energy is released at a high rate due to failure of a component in the system in which the rope is used. Under these conditions, it will recoil violently endangering anything and anyone in its path.

Insofar as can be determined, there has been little test work conducted on synthetic lines to measure the recoil or "snapback" properties. In use as tow lines or mooring lines, this property is highly important because of the potential danger to personnel on deck. Because of this importance, the Field Testing and Development Center was given the project to develop a means of evaluating the relative recoil properties of rope and to conduct appropriate evaluations in representative rope samples.

2.0 BACKGROUND:

Field experience with synthetic lines, principally nylon, has shown that, in the absence of other forces, synthetic lines will recoil directly back on themselves with extreme violence when released under load. To afford a comparative evaluation of the danger inherent in various types of line, a method of measuring the violence of recoil was required. Since recoil is a function of the energy immediately available upon release, a measure of this would be the potential energy stored in the line in its loaded, elongated condition. In which case, a simple measurement of elongation versus load would suffice to determine the potential energy. In the case in question, lines are not pure elastic and complete recovery of the length does not occur immediately. Thus, potential energy is not a true measure of energy immediately available upon release. A better measure of the energy available will be in the form of kinetic energy imparted to the system upon release. Within reasonable limits, it may be assumed that all energy available will be in the form of kinetic energy by the time the free end of the line has passed the zero elongation point. The total kinetic energy of a system is the sum of the kinetic energies of the individual masses.

$$K.E. = 1/2 \sum_{i=1}^{i=n} M_i V_i^2$$

For the system made up of a recoiling line, the mass involved is made up of the various components such as shackles and thimbles plus the evenly distributed mass of the line. Since all parts of the system are not travelling at the same velocity at any one time, it would be necessary to break the line into small segments and measure the velocity of each segment to approximate the kinetic energy of the system.

If a relative large mass is placed in the system at the end of the line, the velocity of this mass will be equal to or greater than the velocity of the line segments. The kinetic energy of the system would still be the summation of the parts.

$$K.E. = 1/2 \sum_{i=1}^{i=n} M_i V_i^2 + \tfrac{1}{2} M_W V_W^2$$

Where M_i and V_i are the mass and the velocity of the line segments and M_W and V_W are the mass and velocity of the large weight at the end of the line. As M_W increases, V_i and V_W will decrease and the weight of the line M_i will remain constant. In which case, a greater portion of the kinetic energy will be in the attached weight and the effect of the distributed mass of the line will become less significant. In this manner, the kinetic energy of the system may be approximated by knowing the mass of the attached weight and the velocity of the weight as it passes the zero elongation point of the line. Then, testing lines of various materials and constructions of equal strength by loading to the same percentage of breaking strength and measuring the kinetic energy imparted to a given mass, a comparative measure of recoil properties may be obtained. Since lines of identical breaking strength are not readily available in the various materials and construction, testing would be carried out on lines of approximate equal strength, and the results normalized using the breaking strength of the line under test.

Previous testing indicated the ratio of loading expressed as a percentage of breaking strength to the elongation expressed as a percent of original length at a given percent of break strength loading is constant from one size to another of the same construction and material. To confirm this, testing would be carried out for lines with breaking strength in the 5000 pounds and 15,000 pounds range.

3.0 TEST APPARATUS:

The range was 200 feet long with an 8 foot high tripod at one end and a winch at the other to apply tensile loads to the test lines. The length of the range was based upon testing 125' samples of line. A high speed (128 frames per second) movie camera was positioned on a line perpendicular to the range at a point 125 feet from the tripod end of the range. This permitted the movement of the end of the test line to be

photographed during recoil as it passed the zero elongation point. Appropriate distance markings were placed on the wall of the building adjacent to the range. This formed a calibrated background for photographing the recoiling line. The calibrated background permitted the measurement of the distance traveled by the moving end of the line by comparing successive frames of the movie film. The frontispiece of this report displays the general location of the recoil range, and shows one line during recoil. Figure 1-A, Appendix A, displays another view of the range with another line in recoil.

A remote reading load cell dynamometer was installed at the tripod or fixed end of the test lines to measure directly the tensile load applied to the line. Since the winch was limited in line pull available, a tackle arrangement was required to increase the line pull to the necessary level. A secondary effect was that this reduced the hauling rate and permitted a finer control on tensioning of the lines. A standard pelican hook was modified by the addition of a release lever which permitted the remote release of the free end of the test lines while under load. With the test range prepared, several preliminary test runs were carried out to verify the feasibility of the intended procedure and to check out the test apparatus. The results of the first test run vividly showed the need for some protection of the tripod which anchored the fixed end of the test lines. The line and weight recoiled with such violence that the support tripod was badly distorted. Figure 2-A, Appendix A, displays the appearance of the tripod after it was hit by one of the smaller lines, only partially loaded prior to release. The violence of the recoil was a revelation to all personnel involved in the test. The tripod was repaired and a protective fence of heavy duty wire mesh was fabricated in front of the tripod, Figure 3-A, Appendix A. This fence lasted for two test runs. The recoiling weight at the end of a small test line punched completely through the fencing each time. Figure 4-A, Appendix A, displays the two holes created by the recoiling weight. A solid steel barrier was fabricated in front of the tripod and although dented several times, proved sufficient to protect the tripod. This barrier is visible at the far end of the range in Figure 1-A.

In addition to the solid steel barrier, a chain arresting gear was also adopted before actual test runs were begun. One shot of heavy, open link buoy chain was connected to the test weight in such a manner that the chains weight arrested the flight of the weight after it passed through the zero elongation point. In this manner, the weight was prevented from striking the barrier wall on all except the most highly loaded lines. The arresting gear is shown in Figure 1A alongside the test range awaiting use. With the recoil test range developed and ready for use, a secondary tensile test facility was prepared nearby to measure the elongation and breaking strength of the various line. The winch tackle and load cell dynamometer of the recoil were adopted for this purpose.

4.0 TEST PROCEDURE:

The following test procedure was adopted and used for each sample of line tested:

a. A 300-foot sample of line was procured directly from the manufacturer.

b. A 10-foot specimen was prepared from each line with an eye splice in each end made in accordance with manufacturer's instructions utilizing properly sized thimbles intended for use with synthetic rope.

c. Using this 10-foot sample, elongation versus load and breaking strength were measured. The rate of elongation imposed on these lines was difficult to control closely because of the type of winch used, but the estimated rate was approximately 3 feet per minute with frequent stops to measure elongation.

d. For each type of line, a 125-foot sample was also prepared again with eye splices at both ends made in accordance with manufacturer's instructions using proper thimbles.

e. The 125-foot sample was then loaded to 50% of its measured breaking strength, relaxed and stowed for at least 24 hours.

f. The 125-foot sample was then loaded to approximately 20%, 40%, 60% and 80% of its measured breaking strength, successively and released under load. A known weight was shackled to the free end for each test. The exact tensile load at the instant of release was recorded for each test.

g. The flight of the weight attached to the free end of the test line was photographed at the zero stretch point for each release and the velocity computed by noting the distance traveled between successive frames of the resultant movie film. Parallax caused by the displacement of the test line from the distance markings on the adjacent building was included in these computations.

5.0 MATERIALS TESTED:

In order to obtain recoil information for a variety of types of line, samples of the following ropes were tested:

ROPE SAMPLES TESTED

Sample No.	Size Diameter (inches)	Material	Type of Construction	Weight lbs/100 ft.	Breaking Strength (lbs.)
1	3/4	Manila	3 Strand	14.2	6000 CR[1]
2	3/4	Manila	Plimoor[2]	16.6	7000 CR
3	7/16	Nylon	3 Strand	5.1	5600 CR
4	7/16	Nylon	Plimoor	5.4	5600 CR
5	7/16	Dacron	3 Strand	5.8	5380 CR
6	7/16	Dacron	Plimoor	5.8	5480 CR
7	9/16	Polypropylene	3 Strand	6.1	5360 CR
8	9/16	Polypropylene	Plimoor	6.2	6000 CR
9	9/16	Doosyn[3]	3 Strand	7.7	5900 CR
10	9/16	Doosyn	Plimoor	7.6	5200 CR
11	1-1/4	Manila	3 Strand	40.2	16,600 CR
12	1-1/4	Manila	Plimoor	39.2	14,250 CR
13	3/4	Nylon	3 Strand	14.3	16,100 CR
14	3/4	Nylon	Plimoor	14.7	14,700 CR
15	3/4	Dacron	3 Strand	17.5	13,800 CR
16	3/4	Dacron	Plimoor	17.2	14,600 CR
17	1	Polypropylene	3 Strand	17.2	15,600 CR

ROPE SAMPLES TESTED

Sample No.	Size Diameter (inches)	Material	Type of Construction	Weight lbs/100 ft.	Breaking Strength (lbs.)
18	1	Polypropylene	Plimoor	18.5	15,200 CR
19	1	Doosyn	3 Strand	22.0	17,700 CR
20	1	Doosyn	Plimoor	25.0	15,300 CR
21	5/8	Dacron	Nolaro[4]	14.3	15,750 CR
22[5]	7/16	Dacron	3 Strand	5.8	5,380 CR
23[5]	3/4	Dacron	3 Strand	17.5	13,800 CR
24	1	Polypropylene	3 Strand	19.3	16,000 BR[6]
25	1/2	Nylon	Double Braided[7]	6.6	7,500 SC[8]
26	1/2	Nylon/ Polypropylene	Double Braided	6.0	7,400 SC
27	5/8	Multi-Filament/ Polypropylene	Double Braided	10.0	8,000 SC
28	1/2	Dacron/ Polypropylene	Double Braided	7.0	6,900 SC
29	3/4	Nylon	Double Braided	17.5	17,500 SC
30	3/4	Nylon/ Polypropylene	Double Braided	13.5	16,000 SC
31	7/8	Polypropylene	Double Braided	16.0	16,000 SC

ROPE SAMPLES TESTED

Sample No.	Size Diameter (inches)	Material	Type of Construction	Weight lbs/100 ft.	Breaking Strength (lbs.)
32	7/8	Dacron/ Polypropylene	Double Braided	21	18,500 SC

[1] Columbian Rope Company, Asburn, New York.

[2] This is a type of plaited construction.

[3] Doosyn is a trade name for a mixed fiber construction which is slightly heavier than the polypropylene.

[4] Nolaro is a type of construction in which the fibers have no lay as does conventional rope. Thus the material has a very low elongation under load and is used primarily as a tension member in standard rigging.

[5] These were samples of line which had been fabricated with the filaments pre-tensioned and it was anticipated that reduced elongation and snapback would result. Test results did not confirm this.

[6] This rope is manufactured by British Ropes Ltd., Charlton, England. This is a polypropylene rope manufactured of staple fibers and has the appearance very similar to that of natural fiber line such as manila or hemp. This is in contrast to the long filament fibers used in normal synthetic rope manufacture.

[7] Double braided construction is made up of a core and cover both of which are hollow construction. The core is made up of an equal number of left hand and right hand strands interwoven singularly. The number of yarns per strand depends on the size of line. The cover is made up of an equal number of left and right hand strands inter woven in pairs or greater. The number of strands and yarns per strand depend upon line size.

[8] Samson Cordage Works, Boston, Massachusetts.

6.0 TEST RESULTS:

The normalized kinetic energies of the lines tested are displayed graphically versus the normalized tensile pull at the instant of release in Appendix B. The results are identified by sample numbers as listed in paragraph 5. Assuming the violence of recoil is a function of the kinetic energy in the system, it is apparent from sample numbers 1, 2, 11 and 12 that manila line has a low recoil over the entire loading range up to the breaking point. It can also be noted in all cases that nylon, as a material, has a relatively high recoil. The test results do not indicate any definite effect on recoil of the type of material or construction for synthetic lines. It is shown that all of the synthetics have recoils of approximately the same order of magnitude. The elongation versus load data shown in Appendix B do indicate that this characteristic is affected by construction and material with nylon showing the greatest elongation under load and manila the least.

7.0 CONCLUSIONS:

Based upon the test results, it is concluded that, over the range of loading, all of the synthetic materials will result in a more violent recoil when released under load than the natural fiber manila rope. If this characteristic were the only factor to be considered, manila would be judged superior. The obvious solution would be to use only manila towing and mooring lines. In this type of usage, the rope's ability to withstand impact or shock loads is of equal or greater importance than its static breaking strength. The shock absorbing ability of the rope is measured by the amount of energy the rope is capable of absorbing up to its breaking point, and in this capability, the synthetics are far superior to the manila. For example, the energy absorption of nylon rope on an equal strength basis is two and a half times better than manila. The superiority in energy absorption is a major factor in the excellent performance and durability of the synthetics for ocean towing and mooring lines because they are able to absorb the rapidly applied strains that come with surge loadings. Although these factors dictate the use of synthetic lines for this application, it is imperative that personnel understand the dangers inherent in their use, and handle with care.

8.0 RECOMMENDATIONS:

Based upon the test results and information from other sources, the following recommendations are made:

a. That the following Factors of Safety on minimum breaking strength be used in sizing synthetic ropes for a given working load.

Factor of Safety

Type of Material	Unfavorable Conditions	Average Conditions
Nylon	10	8
Polyester	10	8
Polypropylene	9	6
Polyethylene	9	6
Synthetic Combination	9	6

This is in lieu of the factor of safety of 5 used for manila in average conditions and 8 for unfavorable conditions. When the synthetics were first introduced, the tendency was to substitute for manila on strictly a strength basis. There are other factors involved, such as chafing, cutting, elasticity, and general mishandling of line. For example, substituting on a strength basis double-braided nylon for manila, a 6" circumference manila would be replaced by a 3-1/2" circumference double-braided nylon. Considering the number of strength members as proportional to the cross sectional area of the rope, there will be approximately three times the number of strength members in manila as in the nylon. Each strength member in nylon must carry approximately three times the load of the strength members in manila; therefore, if failure of one of the strength members in nylon occurs, a much greater percentage of strength loss results than failure of one member in manila.

Referring to the results displayed in Appendix B, the increase in Factor of Safety will reduce the hazard of recoil and the problems associated with elongation under load. For example, the elongation for manila at 20% of breaking strength (working strength based on a Factor of Safety of 5) is approximately 7%. This would compare with double-braided nylon at 12.5% of breaking strength (Factor of Safety of 8) with an elongation of approximately 8%.

There will be some sacrifice of weight saving, ease of handling, and cost reduction, but this will be offset by longer life and increased safety.

b. That a visible "tell-tale" be used to indicate loading on synthetic ropes when they are used as tow lines. The natural fiber ropes provide visual and audible indications of overloading. Most of the synthetics can withstand repeated high levels of loading with no serious effect and no apparent indication of load except a thinning down under load, and it recovers its normal size when unloaded. The critical point of loading is when twisted nylon rope is stretched 40 percent in length and double-braided nylon is stretched 25 percent. Should this point be exceeded, the

line is in danger of parting. The foregoing elongations occur at approximately 90 percent of breaking strength. To insure against loading to the danger point, a simple "tell-tale" consisting of a length of small stuff attached at two points on the loaded line shall be used. For twisted nylon, attach a thirty-nine inch length of small stuff to two points on the unloaded hawser thirty inches apart. The loop of small stuff to be allowed to hang free, and when the hawser is loaded and the small stuff comes taut, the hawser is elongated approximately 30 percent. At this point, the load limit is reached. For double-braided nylon, use a 36 inch length of small stuff, attached 30 inches apart, for a 20 percent elongation limit. If other synthetic materials are used for towing, similar "tell-tales" should be used, adjusting length of small stuff and attaching points in accordance with elongation versus load information.

c. When using synthetics, care should be taken in selecting all components of the system such as thimbles, shackles, blocks and hooks. For example, thimbles used with manila are not satisfactory for use with nylon of the same size, partly because of strength and partly because of the elongation of the eye in which the thimble is used. The old adage, "A chain is only as strong as its weakest link" is very apropos and must be considered, particularly, when substituting for manila with a synthetic.

9.0 COROLLARY TESTING:

As an associated test, a mock-up of a typical small boat protective screen was tested against the recoil of a synthetic tow line. The intent of this secondary test was to verify the adequacy of the protection offered small boat operators in the Coast Guard utility boats. A barrier, similar to that described in Coast Guard Boat Alteration 40-UT-84 dated 5 June 1964, was fabricated in front of the stationary tripod on the test range. This barrier is shown in Figure 5-A, Appendix A. A standard tow line for Coast Guard utility boats is 7/8" diameter, 3 strand nylon line. A 150' link of this line was prepared with a bronze thimble spliced into each end. These thimbles were the type designed for use with synthetic lines and this thimble in the free end simulated a cleat or shackle such as might pull away under tension from a boat under tow.

The line was tensioned to 10,000 pounds (approximately 50% of its nominal breaking strength) and released under load. High speed movies were taken of the barrier mock-up in the path of the recoiling line. Although the frame speed (64 frames per second) was not fast enough to stop the flight of the thimble in the free end of the line, the pictures did show that a bite of the recoiling line looped around the top of the aluminum flat bar in the chain link screen and parted all three shock cord attachments at the screen top. These attachments failed by fracture of the interior rubber strands and by the pulling free of the clamping rings. Either failure would have released the barrier screen, but both occurred simultaneously. The barrier screen then carried away and fell down before

the end of the recoiling line and thimble arrived. The same bite of line which carried away the barrier screen then fouled the frame of the barrier mock-up and bent it badly. The remainder of the recoiling line and thimble then passed through the area where the barrier screen had been, and wrapped the tripod at the end of the range. Figure 6-A, Appendix A, displays the damage done to the barrier mock-up by this test.

10.0 DISCUSSION OF COROLLARY TESTING:

The danger present from recoiling line is hard to appreciate fully without actually witnessing the violence of the snapback of these lines. This is particularly true with the synthetic lines. The 25 and 50 pound weights attached to the free ends of the recoiling line used in these tests often attain speeds in excess of 250 feet per second, as they recoil towards the fixed ends. A simple wire mesh barrier screen provides no protection against forces of this magnitude. A relatively fragile barrier screen installed behind the control station on the Coast Guard utility boats provides little protection to the boat operator and, in fact, may do harm by instilling false confidence in the adequacy of the barrier.

APPENDIX A

Photographs

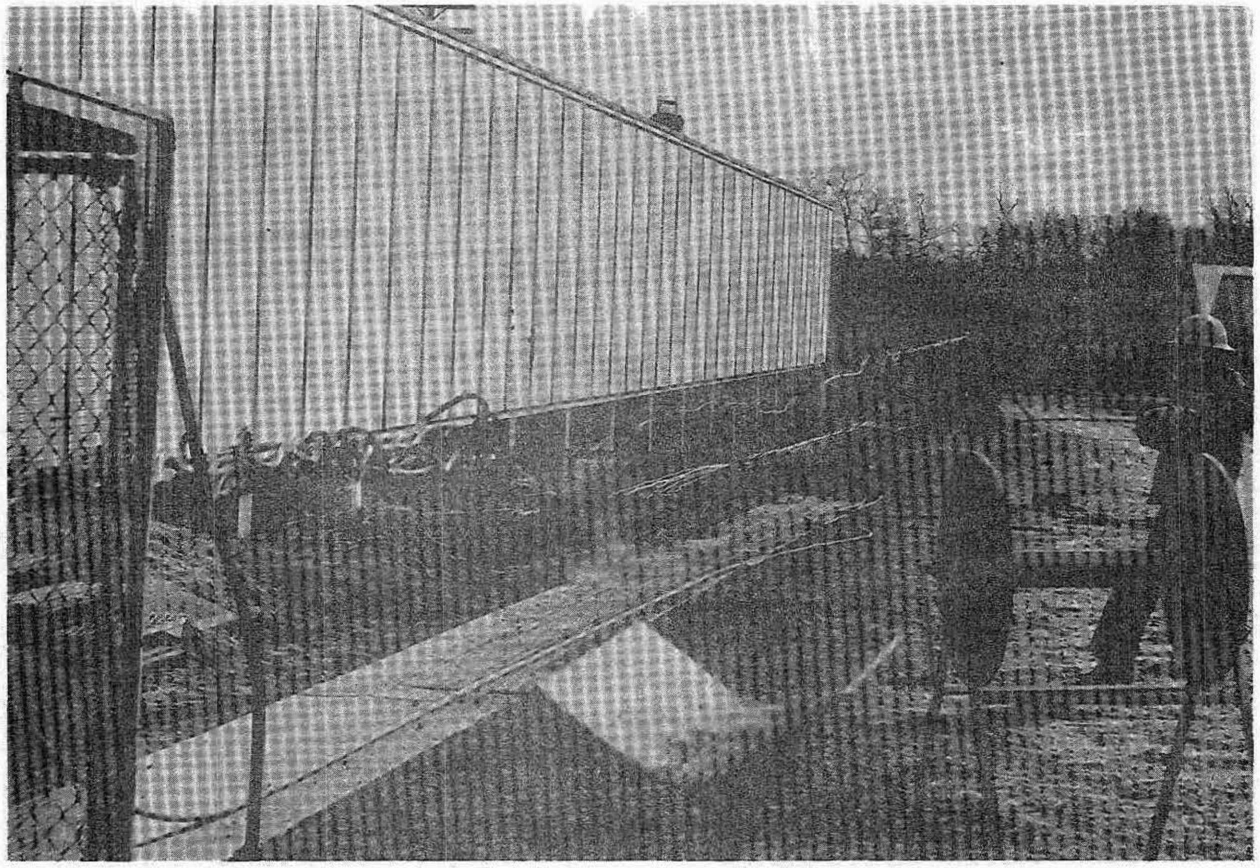


FIGURE 1A - Test range showing line in recoil.

FIGURE 2A - Damage to unprotected tripod caused by recoil of the test line.

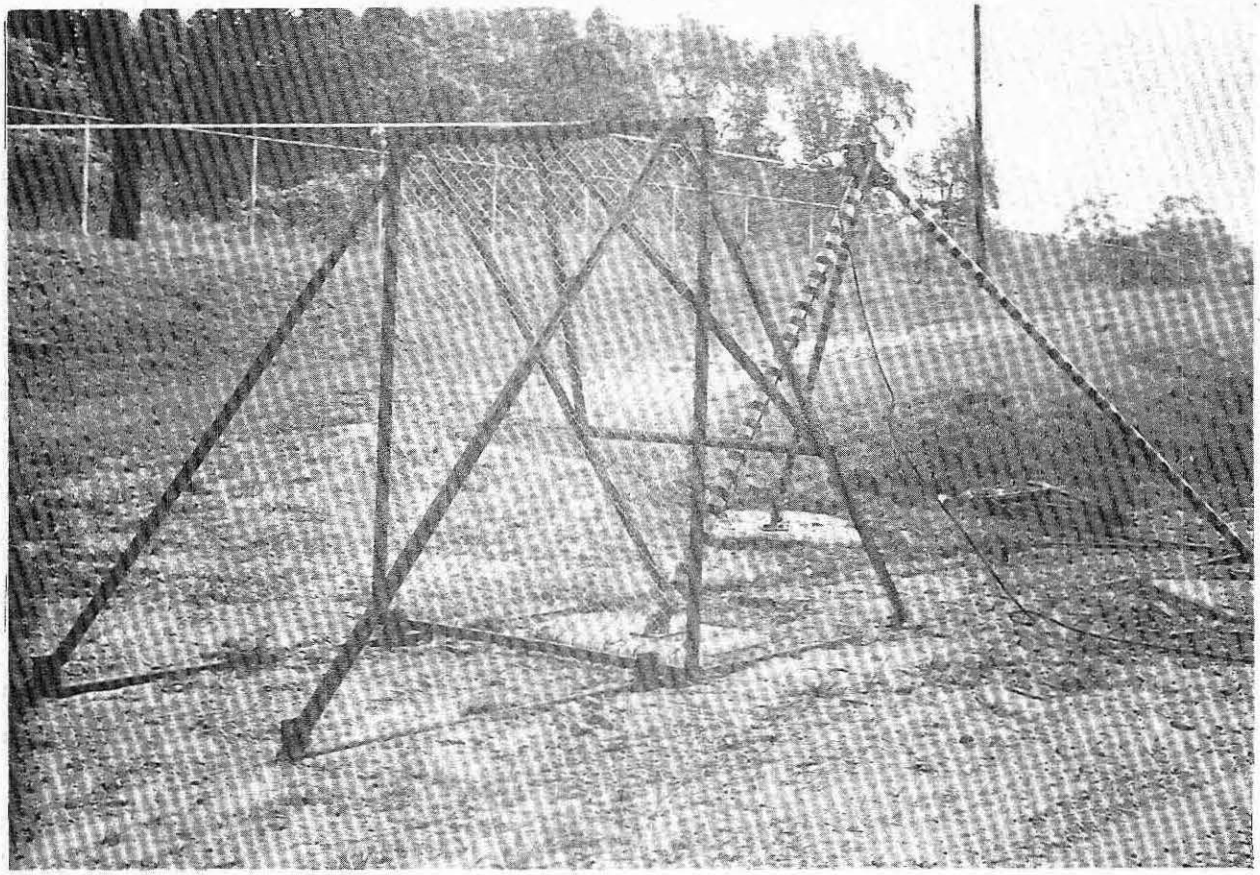


FIGURE 3A - Protective wire screen.

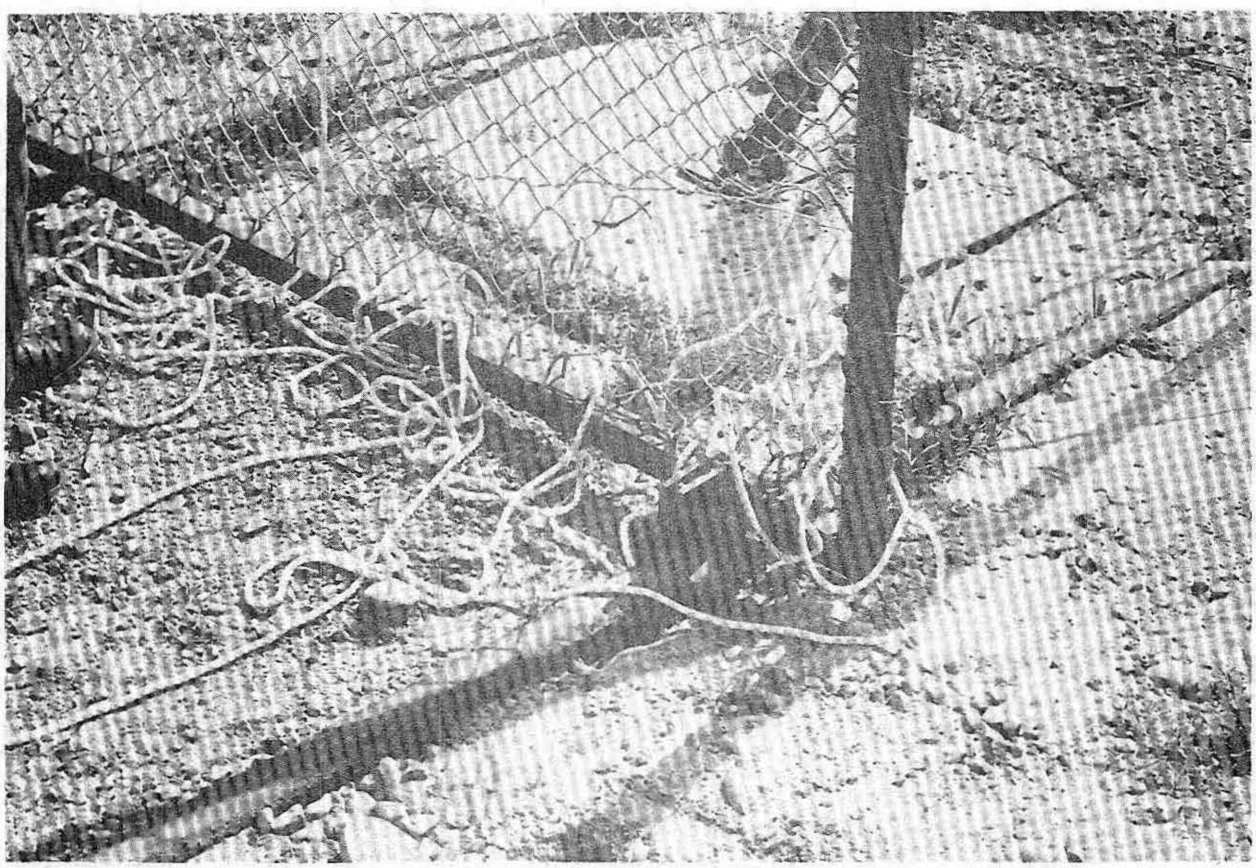


FIGURE 4A -- Damage to wire screen caused by recoil of 3/8" snythetic line.

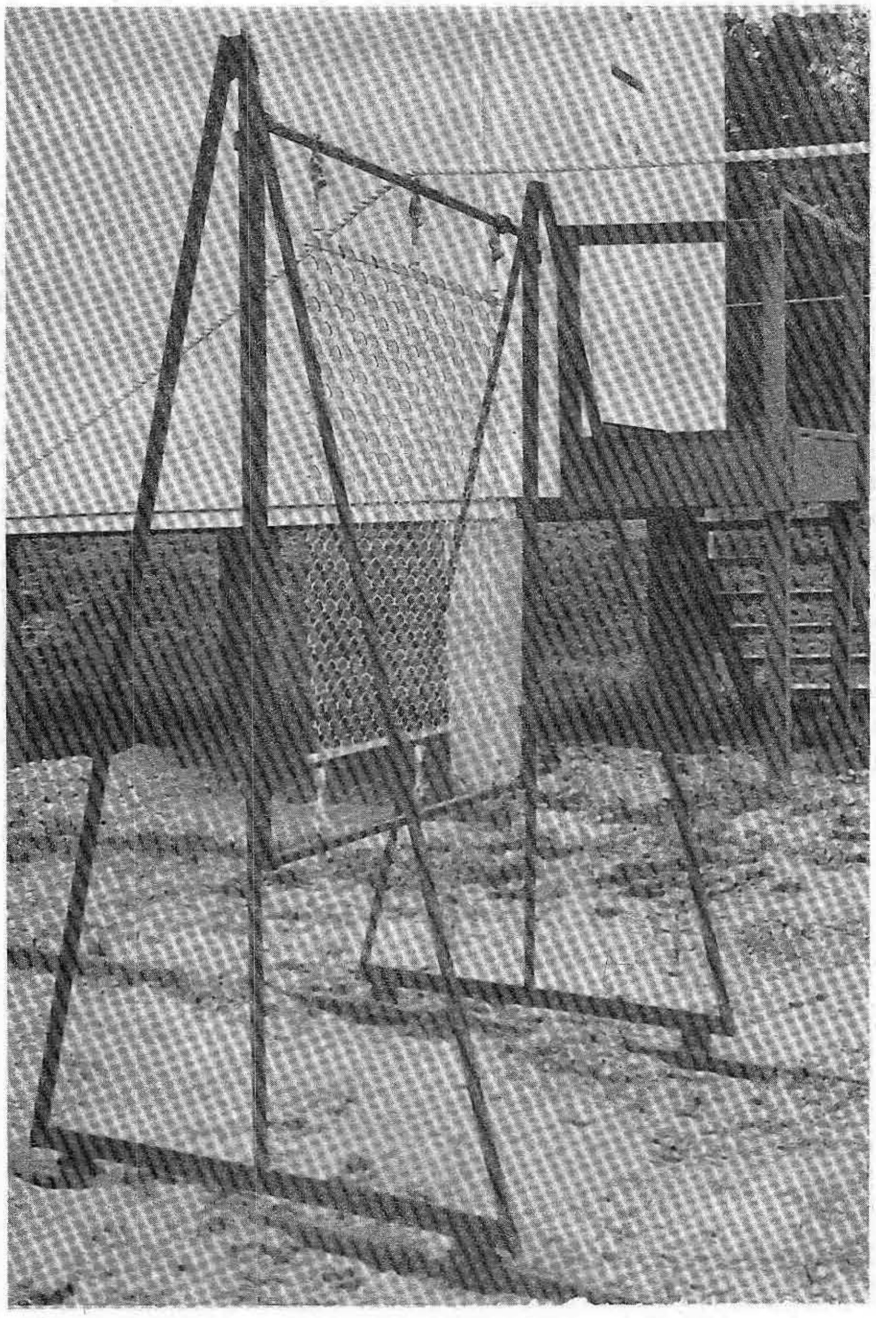


FIGURE 5A - Mock-up of small boat protective screen.

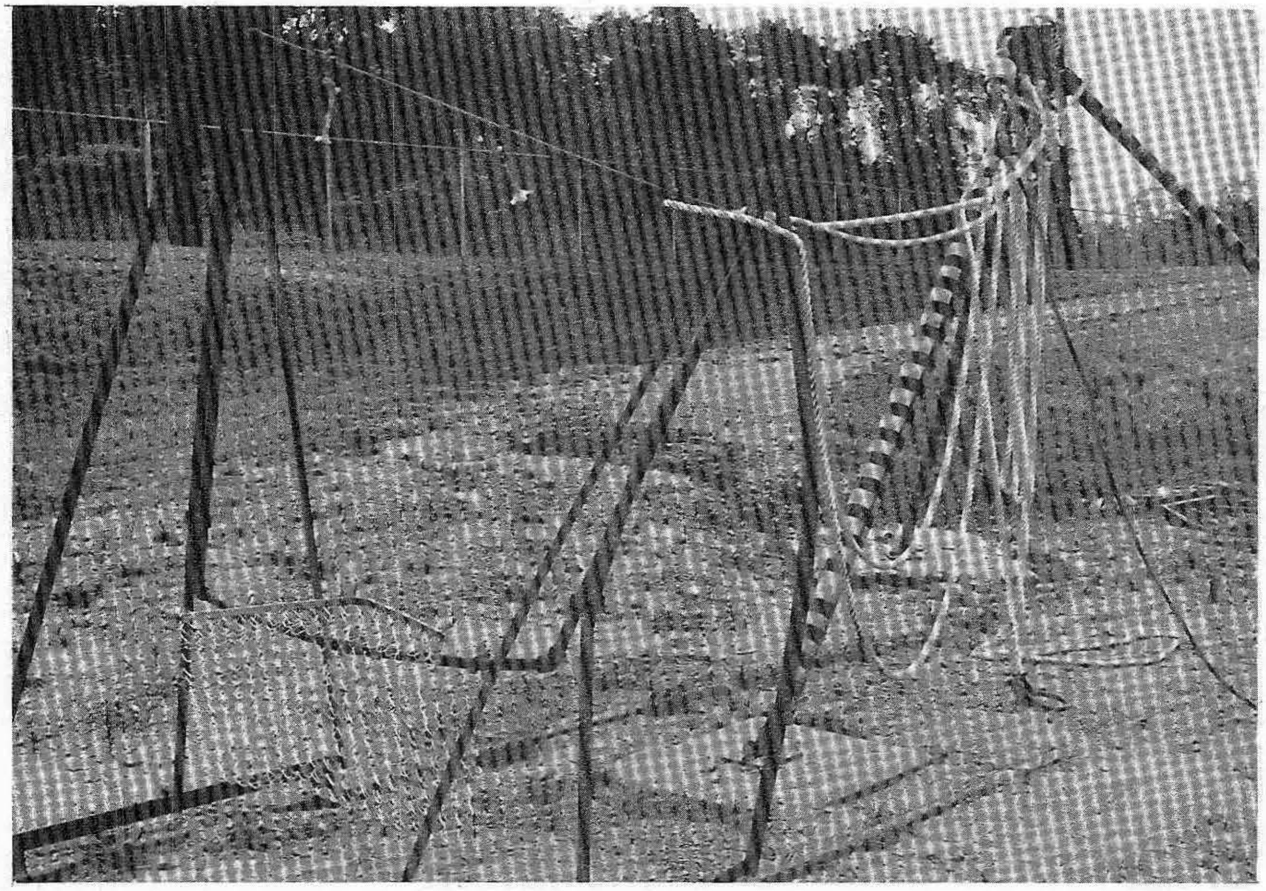
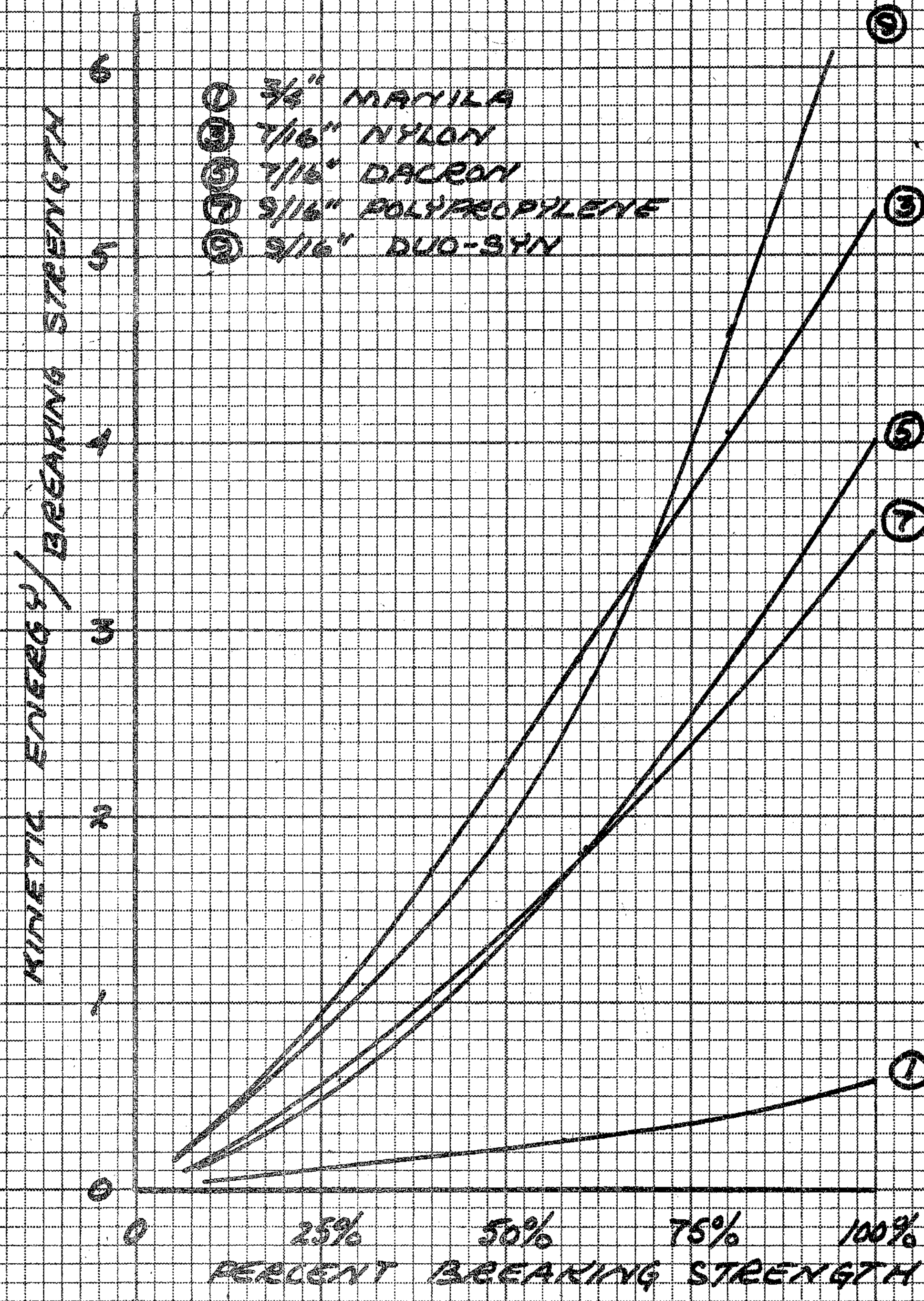


FIGURE 6A - Damage to small boat protective screen due to recoil of 7/8" snythetic line, released at 60% of breaking strength.

APPENDIX B

Figures



COMPARATIVE RECOIL OF THREE-STRAND LINES

PROJECT 3973/01/01

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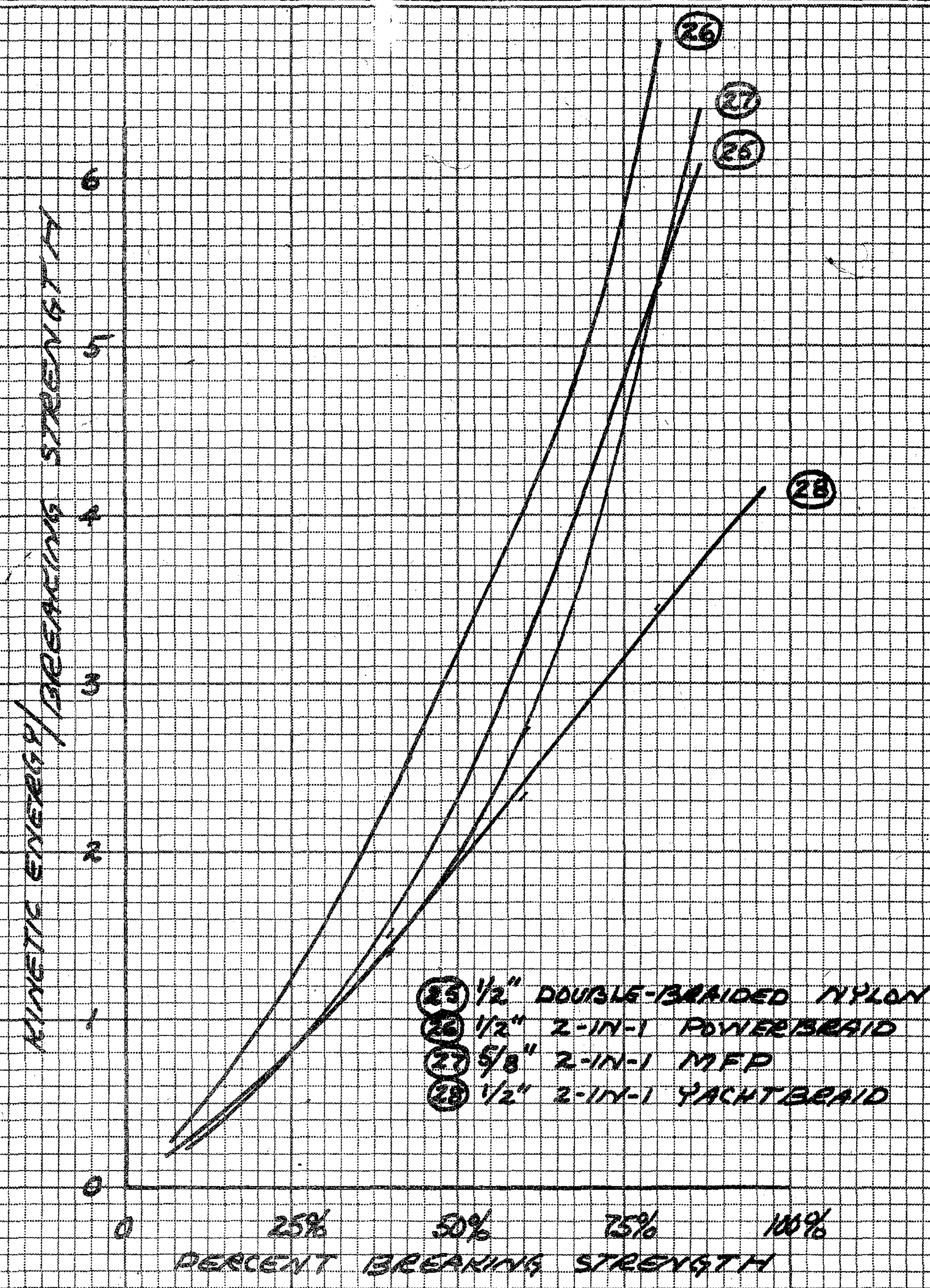

COMPARATIVE RECOIL OF SYNTHETIC LINES

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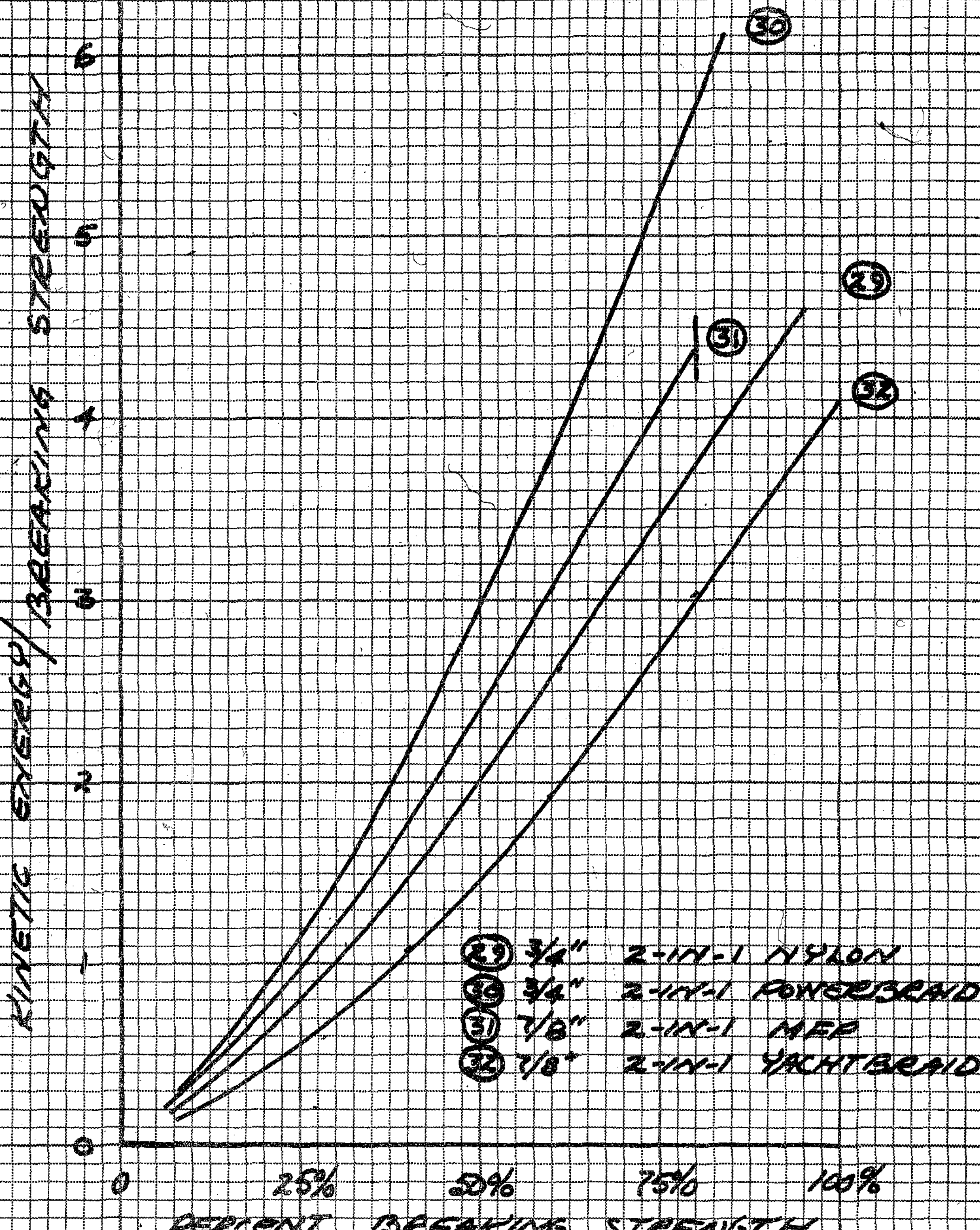

COMPARATIVE RECOIL OF SYNTHETIC LINES

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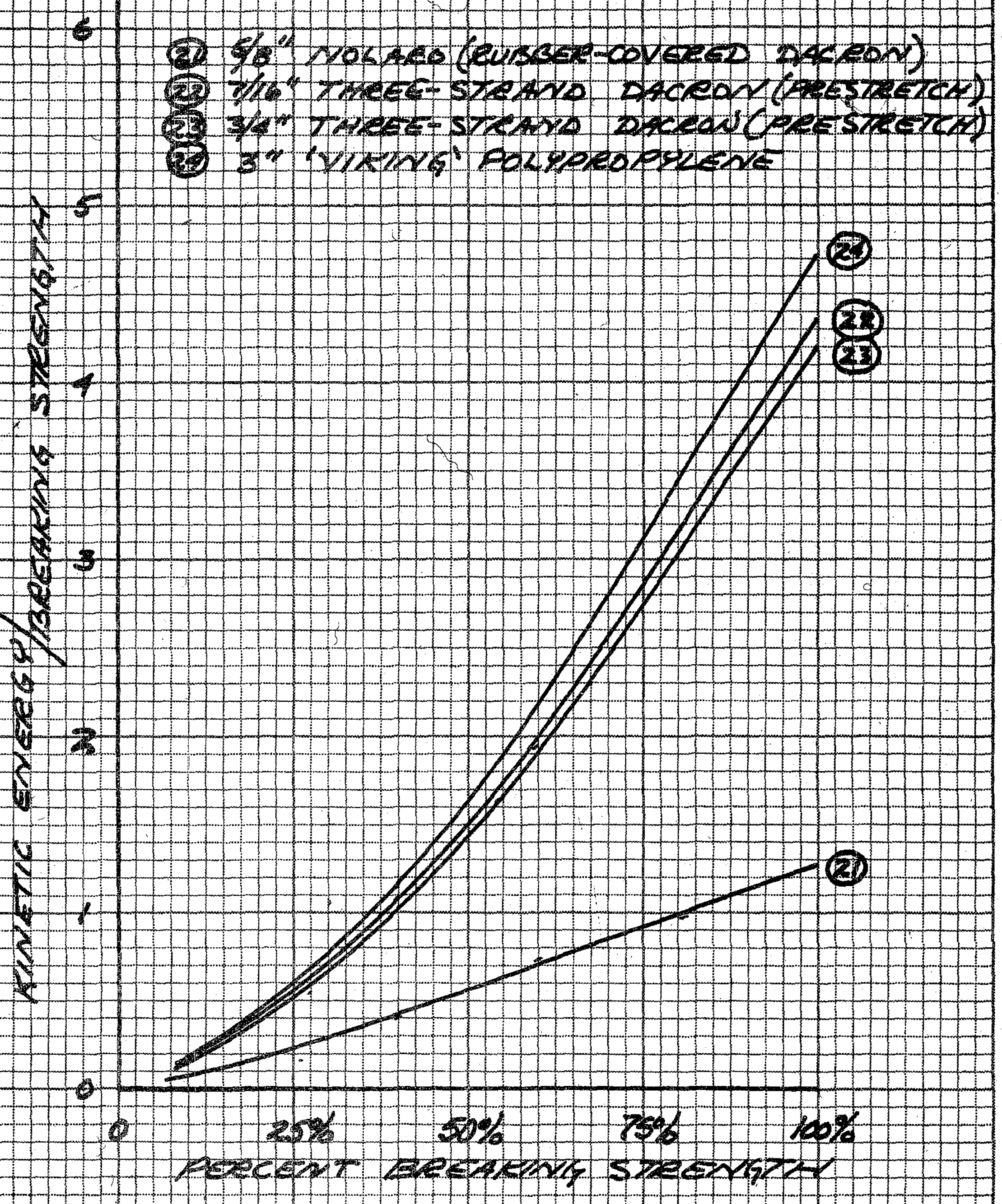

COMPARATIVE RECOIL OF MISCELLANEOUS LINES

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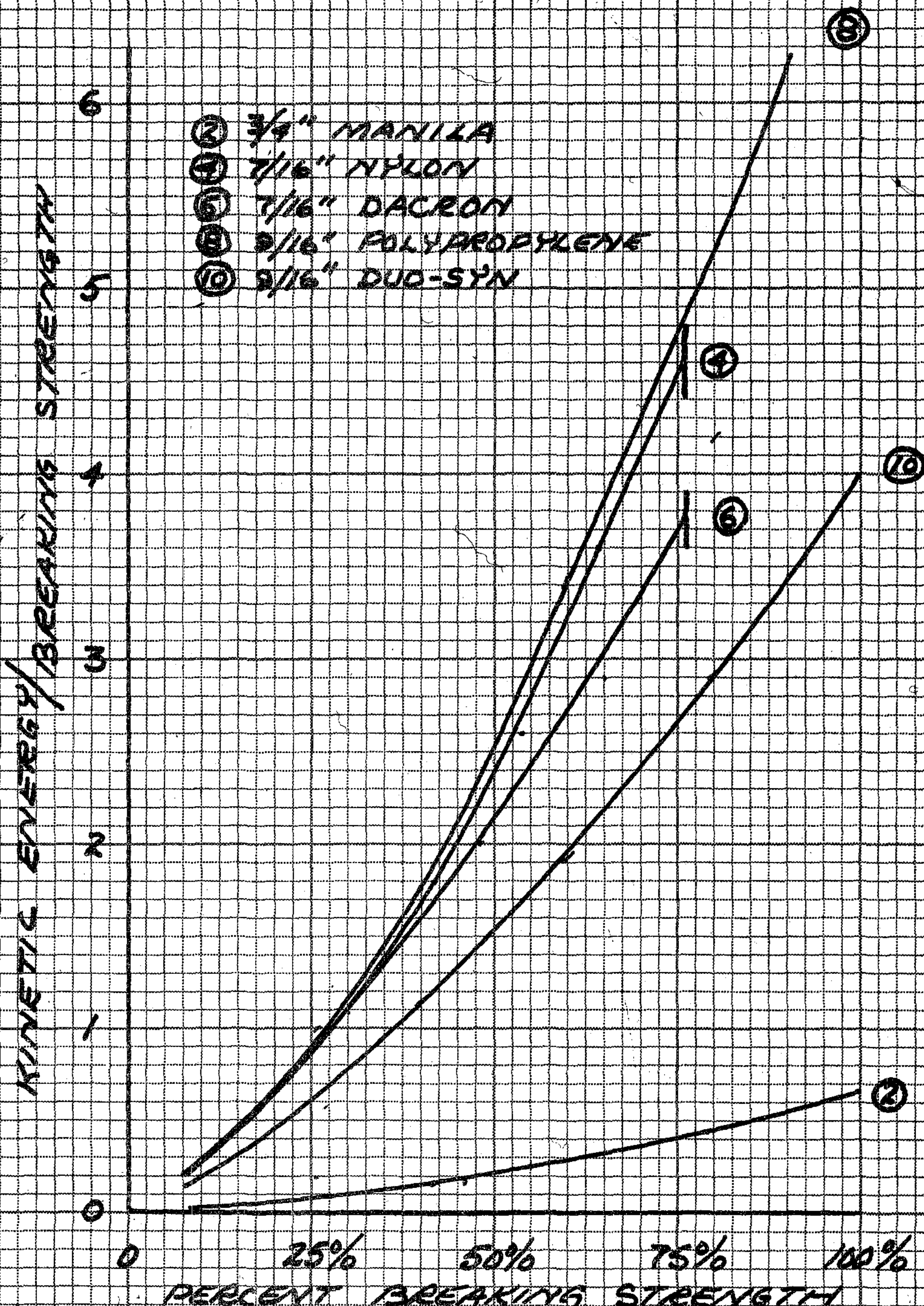

COMPARATIVE RECOIL OF "PLIMOOR" LAY LINES

PROJECT 3973/11/01

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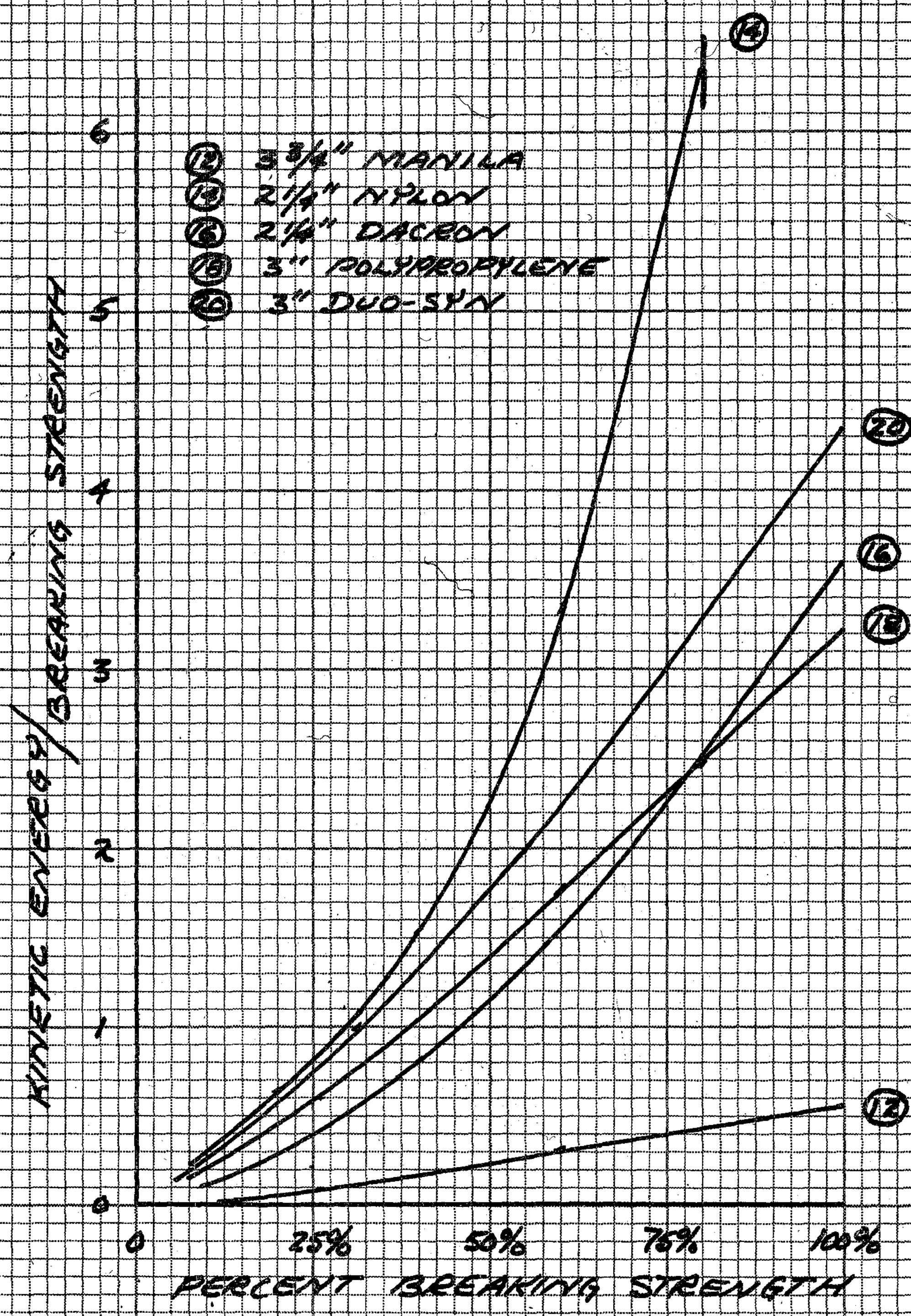

COMPARATIVE RECOIL OF LARGE "PLIMOOR" LAY LINES

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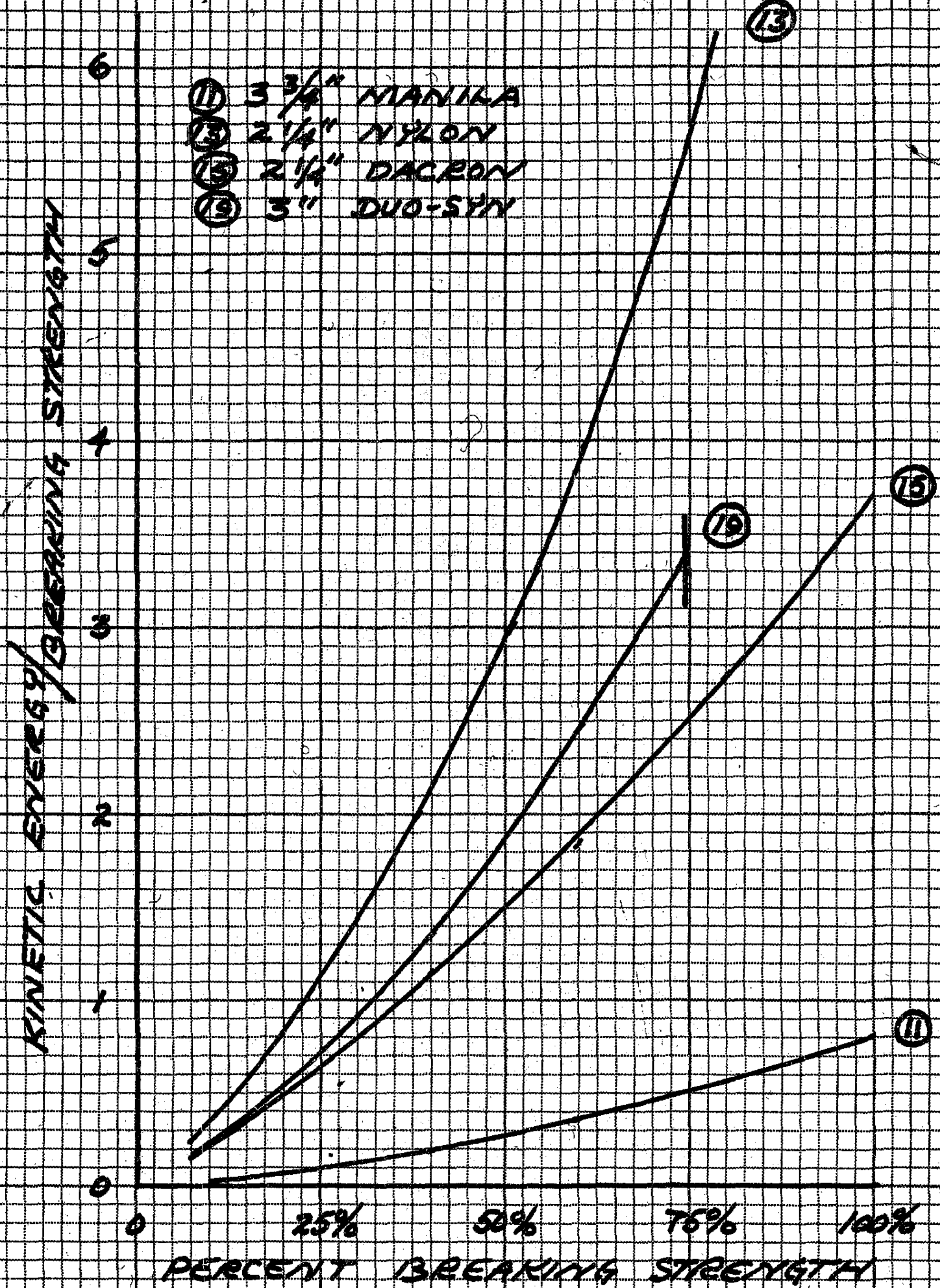

COMPARATIVE RECOIL OF LARGE THREE-STRAND LINES

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TYPICAL
ELONGATION IN
% OF ORIGINAL LENGTH
VS.
LOAD IN
% BREAKING STRENGTH